CHAPTER IX

TECHNOLOGY MATURITY AND TECHNOLOGY DEVELOPMENT

A. TECHNOLOGY MATURITY

All of the work reported in the preceding chapters was performed in order to assess the technical, economic, and energetic feasibility of proceeding with more detailed studies of the geopressured geothermal resource. The preliminary conceptual design and costing activities represented the prime activity for component by component review of the maturity of the technology available for resource utilization facilities. The economics and energetics studies focussed attentions on the areas of major capital and energy investment; these results comprise a useful guide for focussing design in order to reduce initial and operations and maintenance costs and/or investment. The following presents a discussion of the primary technical problems identified.

1. BRINE COMPOSITION AND CHEMISTRY; MATERIALS SERVICE

Clearly, the first technical problem identified is the characteristic of the resource itself. Data is not available to indicate fluid total dissolved solids and salinity profile. However, even if these data were available, the current state of brine chemistry and materials performance analysis does not allow the confident selection of materials and the confident prediction of materials service life, performance, and maintenance problems. The current state of the art requires brine exposure and simulated service environment testing for extended periods of time using the actual brine of the site proposed for commercial utilization. After tests of that nature are complete and the facility has been designed and constructed, numbers of service problems arise. Thus, the operations period becomes the final arbiter for materials selection and design practice; the service period comprises an important and extended applied research activity.

For many materials selection and design tasks, a large number of variables may have an influence on the selection and design task. Exposure time, fluids concentrations, temperatures, flow patterns and velocities, stress concentrations and levels, vibrations, stress cycling, chemical

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interactions between fluids and materials, material phase and grain size, manufacturing processes, scale formation and brine kinetics, electrolytic action, surface smoothness and finish, and presence of trace elements in the brine, which can act catalytically, all are or can be important. Carefully designed and executed experiments, using the actual brines, are important to elucidating some of the important variables for a specific service use and environment. Unfortunately, such studies can delay commercialization for a considerable time if conducted properly.

2. METHANE/BRINE SEPARATION

It is apparent, from discussion of the design of the high pressure methane/brine separators, that factors as brine residence times and the rate at which the brine comes out of solution are uncertainties. The dependence of the separation rate on fluid velocity, fluid pressure, and flow pattern may require study. The amount of pressure drop and enthalpy change during the separation process may be important to separation rates. Data is required for saline fraction carry-over and water vapor carry-over to enable efficient design of facilities for further methane processing.

3. EFFLUENT BRINE DISPOSAL

Economic disposal of brine effluents and non-condensible effluents as H_2S are key problems. Sufficient study of the technology, energetics, and economics of effluent disposal has not occurred. Studies of alternatives to subsurface disposal are yet to proceed. The interaction between the utilization system and the effluent disposal system during emergency conditions deserves study in order to determine the impacts of temperature, flow rate, and/or salinity changes on the disposal system. Sizing of storage capacity to deal with thermal, pressure, or flow rate surges has not been addressed.

4. GEOHYDRAULIC TURBINE DESIGN AND PERFORMANCE

A hydraulic turbine designed for geopressure geothermal applications must face two inimical service conditions: (a) fluids temperature and salinity and (b) methane gas phase formation and possible two-phase flow as a function of pressure drop. The extent with which two-phase flow will occur will certainly be a function of brine residence time in the turbine and the rate at which the methane comes out of solution. Cavitation problems associated with two-phase flow are possible although careful blade design might eliminate or sufficiently mitigate cavitation.

5. PERFORMANCE OF BRINE SERVICE HEAT EXCHANGERS

Heat exchangers for any brine service task--be it vaporizing a secondary working fluid or heating a fluid for supplying process heat directly or indirectly--must be designed to overcome or mitigate scale formation on the brine-side surfaces. The scale formation rates are known to depend on transfer surface material, brine composition, brine velocity, brine pressure, and local heat transfer rate. Other parameters may be important. The hardness of the scale also is significant as are methods for scale removal.

6. PUMPING POWER IN SECONDARY WORKING FLUID PLANT

The lower temperatures expected in geopressured geothermal fluids, based upon current resource assessment results, predicates low efficiency SWF cycles. Heat exchanger design considerations appear to limit secondary fluid candidates. Pumping power is very significant for cooling water and secondary working fluid recirculation. Use of secondary fluid turbines rather than electric motor drives will reduce secondary fluid flow rates some and will correspondingly reduce pumping requirements as well. The economics and energetics of substituting turbine drives for motor drives is not established.

Use of binary mixture secondary working fluids could improve cycle efficiency and correspondingly reduce pumping power. Increases of cycle efficiency, of course, reduce heat rejection as well as reduce investment in fuel production facilities.

7. HEAT REJECTION - POWER PLANT

Because the temperature difference between heat source and heat sink is low, geothermal power generation is much less efficient and requires much greater heat rejection. Efficiencies calculated for the preliminary conceptual designs were about 10%, or about $^1/_3$ to $^1/_4$ that of nuclear or fossil-fired generation units. Thus, heat rejection per kilowatt-hour generated will be approximately $3^1/_2$ to $4^1/_2$ times larger. This very large heat rejection places large demands on water resources, resulting in significant impacts on local water supplies. For secondary working fluid plant, design of integral dry tower/condensers may be an economic solution to the problem. Flash steam plant, on the other hand, may not be as readily adaptable should the condensate not be available for evaporative towers owing to a requirement for reinjection. Less expensive, high efficiency heat transfer surfaces currently available may help solve the problem.

8. HEAT REJECTION - EFFLUENT DISPOSAL FACILITY

Should bypass of the fuel plant and/or the power plant become necessary, heat removal or enthalpy suppression may be required to protect the effluent disposal facility. A surface disposal facility will require less effective thermal degradation of the fluid for routine operation. These problems require immediate attention.

9. SALINE FRACTION REMOVAL

Both the subsurface and surface disposal methods will require removal of solids not in solution prior to fluid disposal. The removal load for surface disposal will be larger as both the fluids pressure and temperature will be lower than for subsurface disposal. The removed saline fraction remains a disposal problem, however. It might be disposed of by injection beneath the cap rock of an unused salt dome as the quantities of solids well be only a fraction of the effluent flow.

10. STEAM TURBINE AND COMPRESSOR TECHNOLOGY

Steam turbines designed for geothermal power plant service suffer static component corrosion attack and scaling and blade service problems. Blades in the middle and rear stages of geothermal turbines may suffer erosion, hydrogen embrittlement, stress corrosion, fatigue failure, and perhaps intergranular corrosion. Blades and shroud bands are sensitive to design, manufacturing process, and heat treating. The presence of quartz crystals or other particulates entrained in the steam results in impact pitting of blading surfaces, especially the leading edges of blades.

Large compressors for beneficiating (upgrading) steam (or compressing steam) appear not to be a standard industry product. If one can make that assumption, then the technology for beneficiation of geothermal steam may have a significant uncertainty. However, the compressor would have a significant advantage over a turbine operating at the same inlet steam conditions--superheated steam, instead of saturated or wet steam --

throughout the turbine stages.

B. TECHNOLOGY DEVELOPMENT

The various technology problems identified in the previous section can be ameliorated through an appropriate program of technology development. A program designed to achieve this objective will contain a mix of systems studies, concept development, experimental investigation, and operational testing. The program should be subdivided into subprograms in such a manner that an efficient and cost effective approach obtains. The subprograms should be sequenced in such a manner as to maximize the probability for success in each successive step by establishing a solid technical basis during the preceeding steps.

1. SITE-SPECIFIC EFFLUENT DISPOSAL STUDY

Perform site-specific effluent disposal studies for both subsurface and surface disposal for those test well candidate sites which cannot be eliminated for production reservoir, geological, or for environmental reasons. The studies would result in "Go/No Go" conclusions for disposal at each site. The preferred site would then be the subject of a more intense study leading through to permitting for potential commercialization.

2. MINOR TEST FACILITY

Construct an inexpensive facility for investigating heat transfer surface service performance in brine environment available from test well(s). This facility should include capability for materials exposure tests in environments designed to simulate some of the actual conditions expected in fuel and power plants. The minor test facility would be partly integrated with the test well fluids separation facility. The minor test facility should be put into operation within three months of the beginning of well testing. The "fuel plant" portion of the facility will have to be installed prior to test well production testing.

3. MAJOR TEST FACILITY

Should the production tests for the test well be favorable and the results obtaining in the minor test facility indicate no serious brine chemistry/materials problems, a major test facility should be constructed.

This test facility would have the capability of investigating and/or testing geohydraulic turbines, pure substance and binary mixture sedondary working fluid cycle technology, flash steam "cycle" technology, fuel plant technology, dry cooling tower heat rejection technology, prototype modules for future pilot plants, and steam compressor and fluids beneficiation technology.

A preliminary conceptual design and costing for a major test facility has been prepared by Brown and Root, Inc., Section 4.1, Appendix A. The fuel plant portion and part of the flash steam cycle loop of the test facility were developed by Dow Chemical USA (see Appendix B, Figures 5 and 6). The secondary fluid cycle would consist of a vaporizer (brine/secondary fluid heat exchanger), liquid knock-out drum, turbine test bed (including water-brake for turbine), condenser, secondary fluid recirculation pumps, cooling tower, and cooling water recirculation pumps. The facility would be fully instrumented with computer data sampling. A flash steam loop, with similar data monitoring, would include flash tanks, turbine test bed, and steam condenser. The fuel supply plant contains a brine test facility (materials tests), a hydraulic turbine test bed (also capable of total flow turbine testing), and methane separation facilities.

Table IX-1 presents the cost distribution for the major test facility. The system is conceived such that it could be built in stages with a subsequent escalation of cost. The facility is capable of supporting the program of developmental, service testing, and operations research necessary preparatory to proceeding with a pilot plant project.

4. PILOT PLANT

Assuming that the test facilities confirm the technical feasibility of electric power generation using the geopressured geothermal resource, then the next step would be construction of a pilot plant. The pilot plant would be expected to provide operational and economic data as well as meaningful reservoir draw-down data as four wells would be required. Dow Chemical USA and Brown and Root, Inc. have prepared approximately 10 MW(e) [gross] pilot plant preliminary conceptual designs and costs for flash steam and secondary working fluid plants, respectively. The Dow plant, estimated to cost approximately $12,691,000, is described in Appendix B, Section IV (A) (2). Brown and Root's design, presented in

Section 4.2, Appendix A, is estimated at $8,989,556.* Each pilot plant uses the same power conversion cycle as its corresponding 25 MW(e) [net] commercial counterpart concept. Fuel plant for either pilot plant is estimated at $15,152,000 if use is made of already installed wells and equipment provided for the production testing facility. Otherwise, the fuel plant would cost $19,086,000.

Neither unit's estimated cost is close enough to the corresponding commercial unit cost to justify calling these plants demonstrations. The demonstration stage may be bypassed if the pilot plant results are sufficiently problem-free and if the geopressured resource's characteristics are reasonably similar to those of western hydrothermal resources currently being considered for demonstration plants.

TABLE IX-1

COSTS FOR MAJOR TEST FACILITY

ITEM:	
Flash Steam System	$ 290,165
Propane/Brine System	1,043,317
Energy and Heat Rejection System	239,746
Instrument and Control System	858,689
Electrical System	330,342
General Facilities	1,348,399
TOTAL, POWER TEST FACILITY	4,110,658
Fuel Supply Plant	3,827,000
TOTAL ENTIRE FACILITY	$7,938,000

*Addition of a geohydraulic turbine/generator set and two lower pressure (300 and 150 psia) methane separators (to put the two pilot plants on the same basis and to match the fuel plant) will cost an extra $809,000 [estimate by the University of Texas at Austin].